Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/5620-95-7648

Data Collection at the Lockheed Santa Cruz Facility Using Midwave Hyperspectral Imagers

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February 8, 1995

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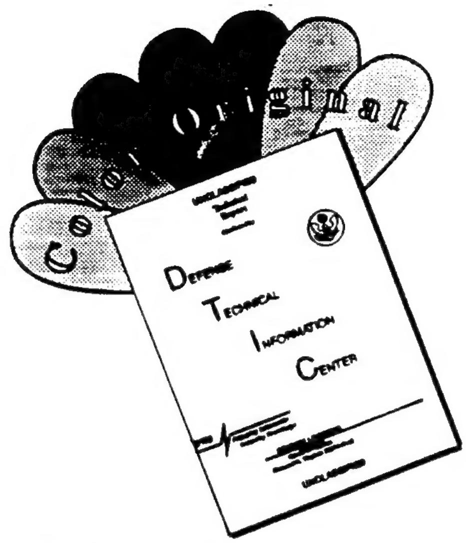

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 8, 1995	

4. TITLE AND SUBTITLE

Data Collection at the Lockheed Santa Cruz Facility Using Midwave Hyperspectral Imagers

5. FUNDING NUMBERS

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/5620--95-7648

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

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**Lawrence Livermore National Laboratory, Livermore, CA 94550

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

From September 12-15, 1994, two midwave hyperspectral imagers (the Infrared Multi-spectral Sensor (IMSS) of Pacific Advanced Technology and the Livermore Imaging Fourier Transform Infrared Spectrometer (LIFTIRS) of Lawrence Livermore National Laboratory) made measurements of particular patches of forest background and a Lockheed Santa Cruz Facility test stand at various times of day and observed the firing of the rocket engine from a sensitive piece of hardware mounted in the Lockheed test stand. The hyperspectral image cubes of the same patch of background observed at various times will be used to investigate the temporal nature of the constituent-temperature interaction. The data of the rocket firing was collected as part of a classified program of the U.S. Army Missile Command. Two sets of data cubes taken of the same background region by IMSS and LIFTIRS simultaneously will be used both to compare the two instruments and to aid in instrument characterization. This paper describes the instruments used in this data collection, the types of backgrounds observed and the experiments performed, and the data collected.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Infrared Field measurements Midwave imaging spectrometers	15
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

CONTENTS

DATA COLLECTION AT THE LOCKHEED SANTA CRUZ FACILITY USING MIDWAVE HYPERSPECTRAL IMAGERS

1. INTRODUCTION

From September 12-15, 1994 two midwave hyperspectral imagers made measurements of particular patches of forest background and a Lockheed Santa Cruz Facility test stand at various times of day and observed the firing of the rocket engine from a sensitive piece of hardware mounted in the Lockheed test stand. One imager was the Infrared Multispectral Sensor (IMSS) of Pacific Advanced Technology. The other was the Livermore Imaging Fourier Transform Infrared Spectrometer (LIFTIRS) of Lawrence Livermore National Laboratory. The hyperspectral image cubes of the same patch of background observed at various times will be used to investigate the temporal nature of the constituent-temperature interaction. An additional use of this data will be the development of techniques to handle large volumes of hyperspectral image data. The data of the rocket firing was collected as part of a classified program of the U.S. Army Missile Command. Two sets of data cubes taken of the same background region by IMSS and LIFTIRS simultaneously will be used both to compare the two instruments and to aid in instrument characterization. The data collection was a successful collaboration between the Advanced Concepts Branch of the Optical Sciences Division of NRL and groups from Pacific Advanced Technology and Lawrence Livermore. This paper describes the instruments used in this data collection, the types of backgrounds observed and the experiments performed, and the data collected.

2. MIDWAVE IMAGERS

IMSS

The IMSS instrument is a dispersive hyperspectral imaging spectrometer using a new and innovative technique invented by Pacific Advanced Technology, "Image Multi-spectral Sensing". The IMSS instrument uses a 128 x 128 InSb FPA built by Amber Engineering as the detector. The prototype configuration of the IMSS instrument is tuned for a peak performance at 3.9 μm with a f/3.5, 160 mm focal length lens system, spectral coverage from 2.5 to 5.0 μm, and a measured spectral resolution $\Delta\lambda/\lambda$ of 0.33%, (6 cm^{-1}). The IMSS can step through approximately 320 spectral bins per micron. The field of view of the instrument is 2.5° with an IFOV of 0.3 mrad. The instrument can collect a full spatial-spectral cube of 128 x 128 pixels from 3 to 5 μm in less than 2 seconds. The noise equivalent spectral irradiance, (NESI), has been measured at 4 x 10^{-4} w/cm^2-sr-μm.

A picture of the IMSS prototype is shown in Fig. 1 and the IMSS sensor as deployed at Santa Cruz is shown in Fig. 2.

LIFTIRS

The instrument uses a specially modified two-beam interferometer as part of the fore-optics of an InSb focal plane array (128x128). The spectral resolution and bandpasses can be varied according to need. As configured at this collection, the instrument provides high spectral resolution (nominal 0.02 μm)

Manuscript approved October 5, 1994.

spectral images in the 3-5 μm infrared band. The collection time for the background images was approximately 10 seconds. For the static rocket firing a sub-image (32x32) was used and the integration time was reduced to 60 μsec to avoid saturating the plume pixels. The IFOV is 50 μrad per detector giving a FOV of 3.7° for the background images and 0.92° for the static firing. The Santa Cruz measurements represent the first use of the LIFTIRS sensor in the field.

A photograph of the LIFTIRS during lab testing is shown in Fig. 3 and as deployed at Santa Cruz in Fig. 4.

3. SANTA CRUZ SITE

The Lockheed Santa Cruz Facility is located on the ridge of Ben Lomond mountain northeast of Santa Cruz, California. The terrain at the facility is extremely hilly with numerous large peaks separated by deep depressions. The soil consists of fine powder mixed in with large amounts of cracked granite. The hills are covered with dense new growth pine forests.

The Lockheed test stand used for the rocket firing is located at the peak of one of the hills. The test stand is a steel structure which can be open in front and back and contains 5 platform levels with a circular opening in the center which allows the placement of rocket hardware at any platform level. Underneath the test stand is a concrete trough in which water is injected into the flame to mitigate the inherent dangers in the use of hazardous materials. In addition to the instruments described in this paper there was a suite of sensors of all types on the test stand itself and on the hill one hundred yards directly in front of the test stand. All of the instruments on the test stand and the near hill were operated remotely or automatically using a pulse trigger during the firing.

The measurements described in this paper were obtained by imagers placed on the top of a hill at an elevation of 2000 feet above sea level and at a range of 0.8 km from the rear of the test stand at an elevation of 2058 feet. The hill was a barren outcropping of rock approximately 50 feet higher than the surrounding terrain. The height of the hillock allowed an almost unobstructed view over the local pine trees in almost all directions. The test stand was located ESE of the hillock across a tree covered valley with the back doors of the stand nearly perpendicular to the line of sight.

4. EXPERIMENTS

The primary instrument used to investigate temporal variations in the constituent composition of images was the IMSS sensor. Four distinct background patches (each corresponding to a 2.5° field-of-view were selected. One background patch (shown in Fig. 5), which is designated as experiment A, included the entire test stand, a portion of the sky above the stand and the tops of the pine trees located in front of and below the stand. Experiment B, shown in Fig. 6, corresponds to a patch of background which includes a pine covered ridge SSE of the observation hill at a range of approximately 1 km, a second ridge beyond the first and Monterey Bay. The ridge at 1 km distance has a dirt road traversing the width of the field-of-view. The dirt road is banked, giving many pixels with powdered soil as the only constituent. Experiment C, shown in Fig. 7, is another portion of the same ridge just east of B. In C the dirt road appears to have no bank, so that it appears as a thin strip in the image. C also includes the farther ridge and the Monterey Bay. Experiment D, shown in Fig. 5, is a patch of background just to the left (from the observers point of view) of the test stand, containing a drainage trough made of gunite, several storage tanks, an aluminum shed used to house a diesel engine, a patch of grass with a lone tree, and the trees on the slope below the test stand.

A typical sequence of measurements would be to collect an image cube at each of the locations A-D. The alignment of the IMSS sensor would be adjusted after each experiment to the next field-of-view. The sequence was repeated typically at one hour intervals. The exact sequence of the experiments was often altered to allow the measurement of registered images at the end of one sequence and the beginning of the next sequence. On Sept 14 between 3 and 4 PM experiment B was performed at 5 minute intervals. During the firing of the rocket engine (at 10:30 AM on Sept 15) experiment A was performed. Following the rocket firing, Experiment A was performed at 5 minute intervals for 50 minutes. A summary of the experiments performed by the IMSS sensor is given in Table 1.

LIFTIRS collected 12 data cubes: two 128 x 128 x 100 image cubes at 7 PM Sept 14 and 2 PM Sept 15 and ten 32 x 32 x 100 cubes of the test stand alone during the firing. The large cubes included the fields-of-view of IMSS experiments A and D. The B and C sites were not visible from the vantage point of the Livermore truck.

Experiment A (the test stand) was designed to monitor the status of the rocket hardware at various stages prior to and during fueling, and during and after firing. Measurements were taken during various stages of the fueling process which took place on Sept 13 and 14.

Experiments B and C were designed to test change detection algorithms and linear mixing models. Experiment B contained two well defined constituents (soil and trees) with many fully resolved pixels of each constituent. Two additional constituents which did not remain constant are ocean (Monterey Bay) and clouds (over Monterey Bay). Experiment C contained the same constituents, in different proportions. Linear mixing will be tested by using experiment B to predict the observations in experiment C.

Experiment D contains many constituents, both natural and man-made. Diurnal cycles of D will be used to study the intricate interaction of the various constituents.

The weather conditions during all of the experiments were ideal. The skies were always cloudless. The temperature ranged from the low 60s (Fahrenheit) in the evening to the mid 80s at mid afternoon. The winds were light to calm and generally in an easterly direction. Humidity was low. Meteorological readings were taken at the test stand site during the entire period of the experiments and are available.

5. THE DATA

A small sample of the data taken during the Santa Cruz collection is presented here. In all, 90 data cubes or 1,217 MB of data were collected using the IMSS sensor and 12 data cubes totaling 200 MB were collected using LIFTIRS.

IMSS

The IMSS sensor easily performed the rapid sequences of experiments. However, some difficulty was encountered in measuring the plume during the static firing. Pre-firing estimates for the expected radiance based on plume temperature were too low, so that even with the lowest integration time of 1 msec and a decreased aperture the pixels at the center of the plume saturated. It is expected that the plume specrum may be recoverable from the unsaturated side-lobe data.

An example of an image from Experiment B is shown in Fig. 8. This spectral image was taken at 8:17 PM with a spectral bandwidth of 0.04 µm centered at 4.775 µm. In Fig. 8 we indicate the positions of the various consituents: the gravel/dirt road, pine trees, the fog bank over Monterey Bay, and sky. The spectra from two fully-resolved pixels one containing trees and the other the gravel/dirt road are given in Fig. 9. The time of this measurement was close to thermal crossover. Therefore there is very little contrast between the dirt road and the trees. The small temperature difference between the two is evident in the separation of the spectra between 3.6 and 4.0 µm.

LIFTIRS

The performance of the LIFTIRS sensor in its maiden field test was exceptional. Fig. 10 shows a spectrum at a single pixel of a local flat field (blackbody source) taken at a resolution of 0.04 µm. The y axis units are of estimated SNR, showing the excellent performance of the system. Fig.11 is a mid-wave image of the test stand area, including Experiments A and D. The scale in the image is related to the total integrated spectral intensity between 3.5 and 4.5 µm. Figure 12 is an image from the same cube showing the spectral intensity at 4.76 µm. Both these images exhibit instrumental artifacts. No attempt has been made to remove these in the preliminary analysis. Fig. 13 shows a comparison of two pixels from the image cube used in Fig. 11. Point A is a fully resolved pixel of gunite and B a pixel in the grass next to the gunite. This figure indicates the wealth of spectral information available in the LIFTIRS data.

The instrument artifacts show in Figs. 11 and 12 appear to be a pattern noise of as yet undetermined origin. Attempts will be made to eliminate this noise from the data before further processing. However, this noise should not interfere with analysis to estimate spectral correlations.

CONCLUSIONS

The data collection conducted at the Santa Cruz Facility was very successful. The four goals of the effort were achieved: 1) hyperspectral infrared measurements of the plume from a piece of hardware of interest, 2) diurnal observations of specific background areas using an IR imager, 3) simultaneous observations of two imagers of potential use to JMSP (LIFTIRS and IMSS), and 4) the acquisition of a large volume of hyperspectral image cubes.

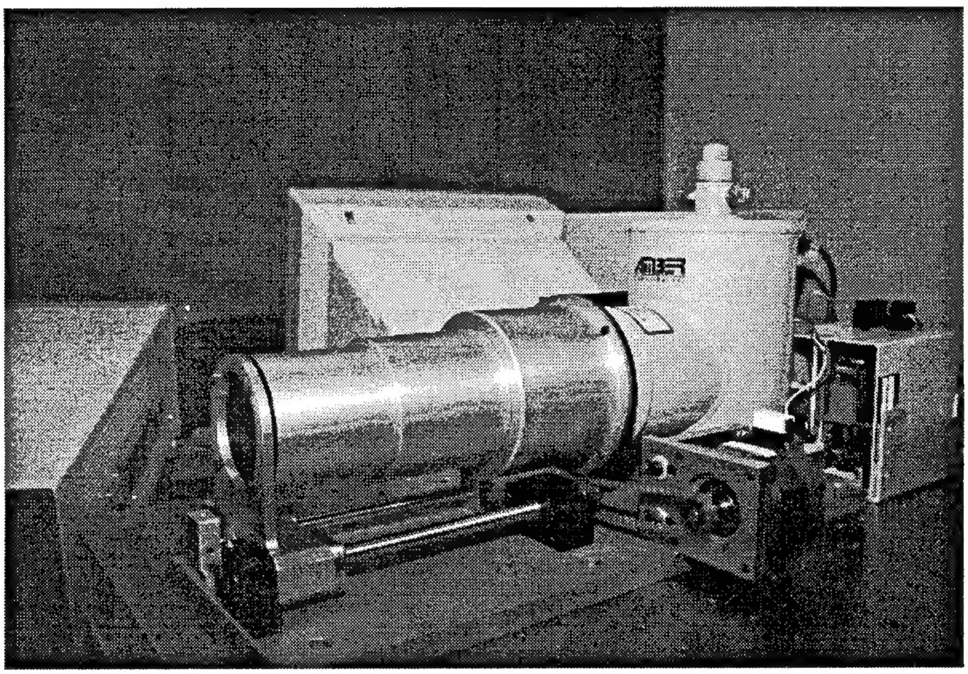

Fig. 1 — The IMSS instrument for space surveillance

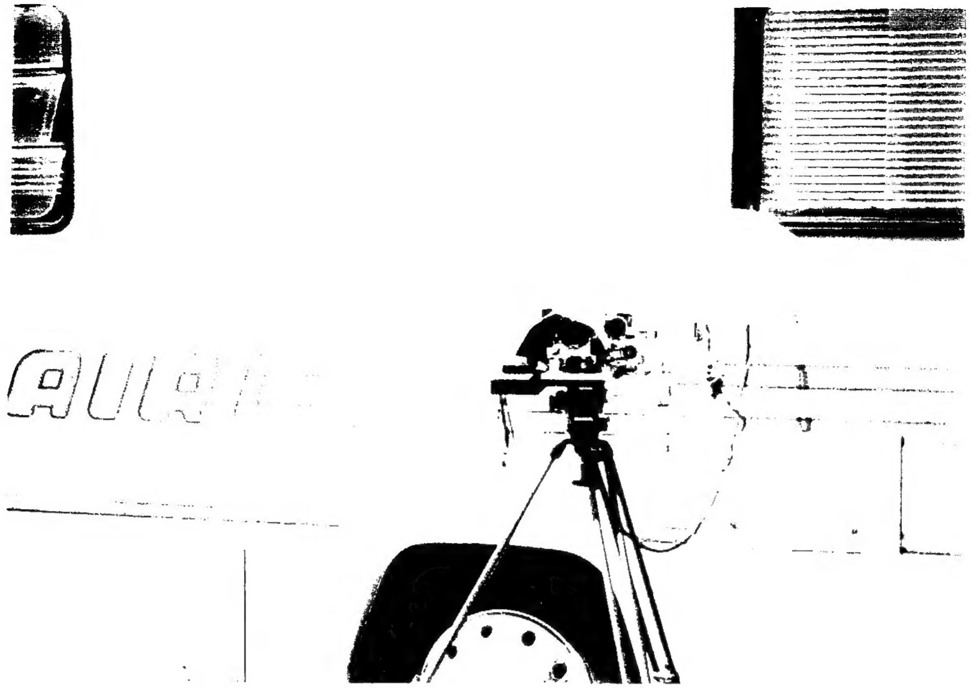

Fig. 2 — The IMSS sensor as deployed during the Santa Cruz data collection

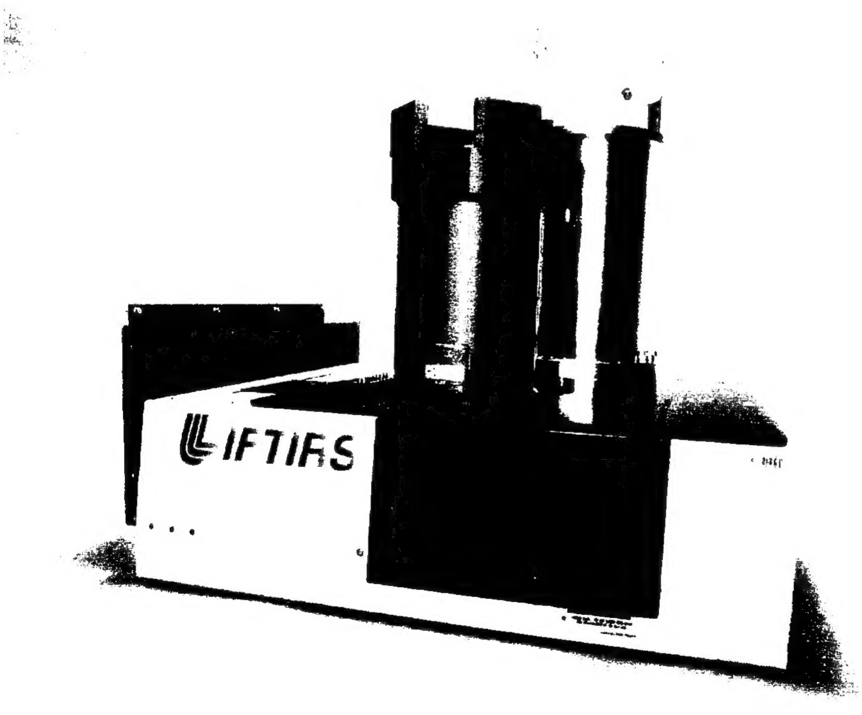

Fig. 3 — LIFTIRS during lab testing

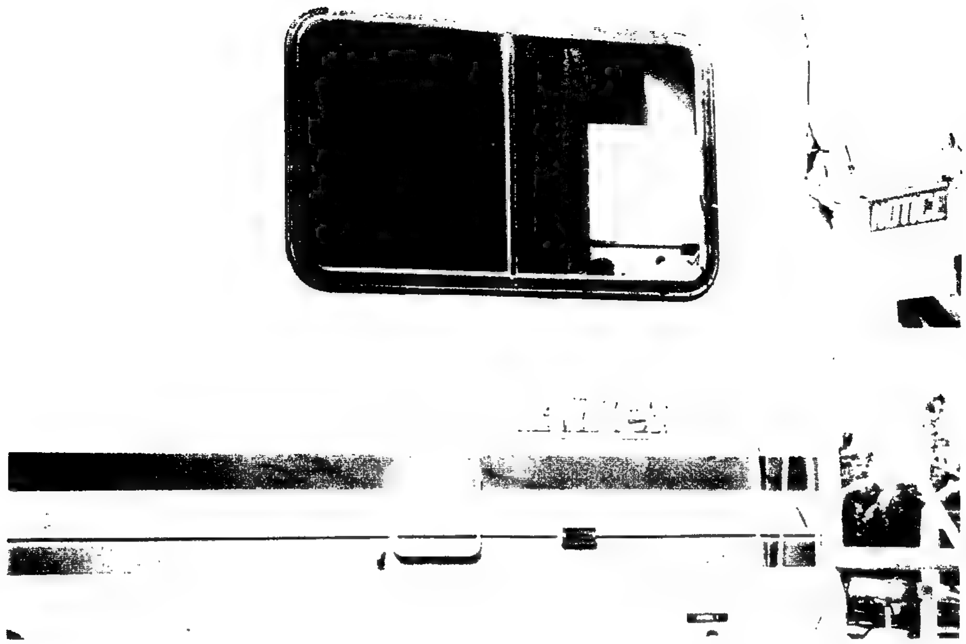

Fig. 4 — LIFTIRS as deployed during the Santa Cruz data collection

Fig. 5 — The view of the test stand from the position of the IMSS sensor. Experiment A includes the test stand. Experiment D is to the left of the stand. Both experiments are outlined.

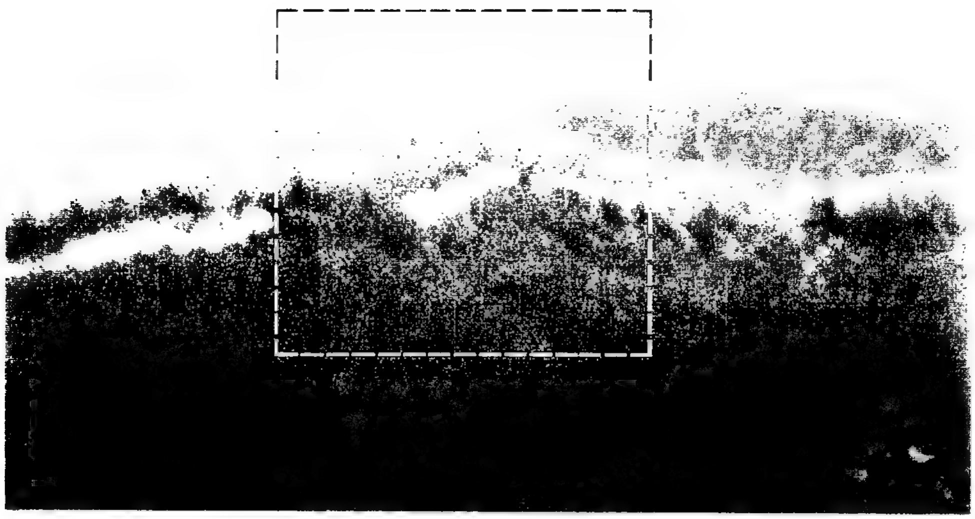

Fig. 6 — Experiment B (outlined) as viewed by IMSS

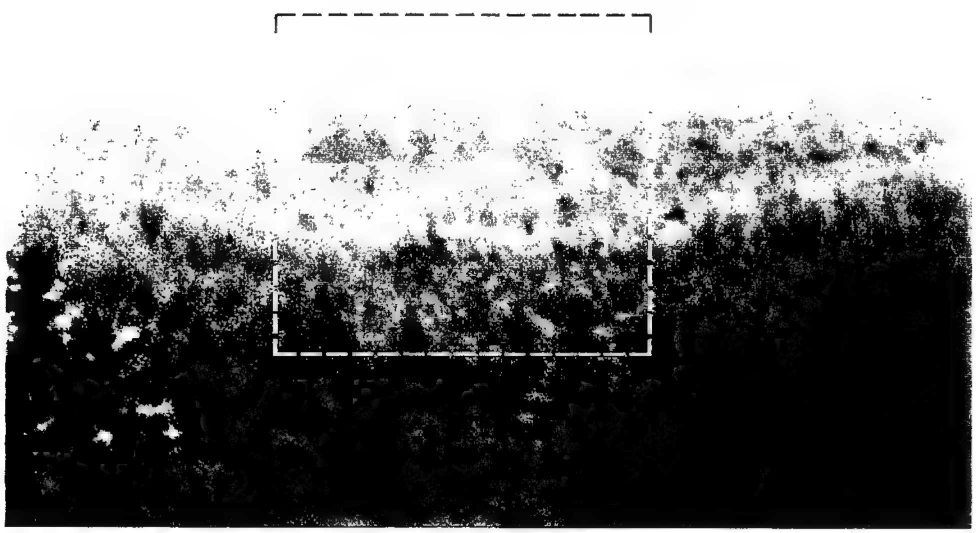

Fig. 7 — Experiment C (outlined) as viewed by IMSS

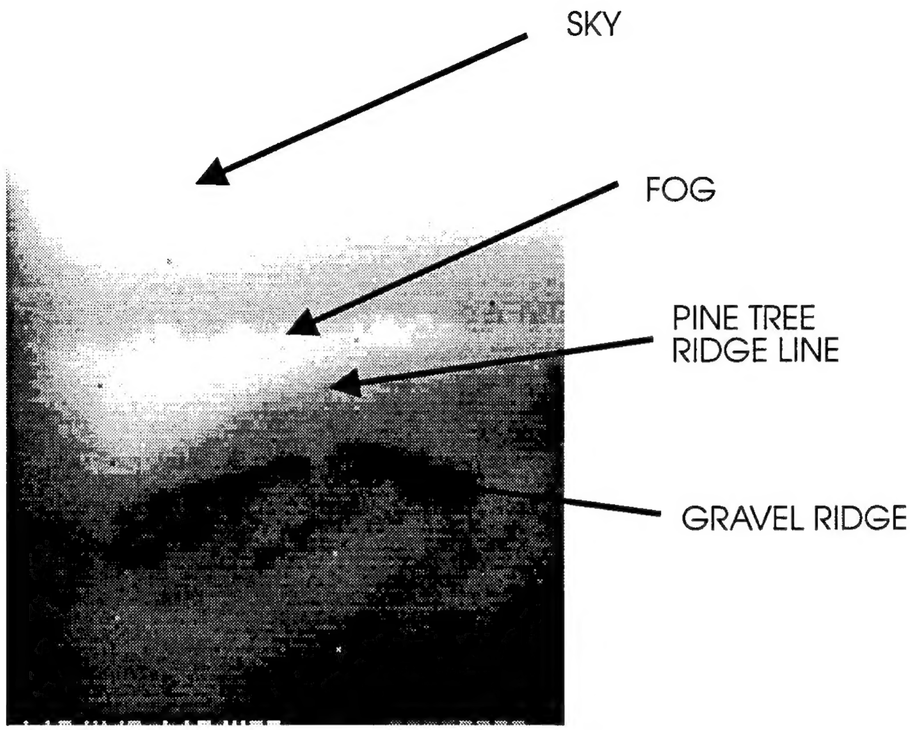

Fig. 8 — Spectral image of location B taken at night

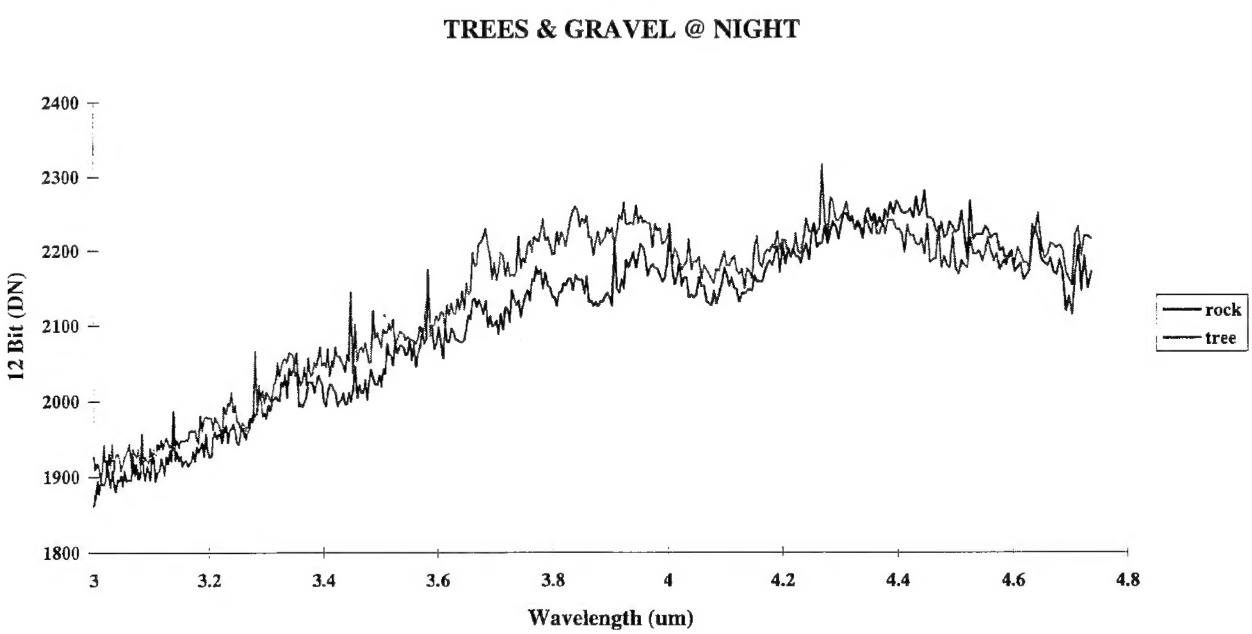

Fig. 9 — Spectrum of pine trees and gravel taken from image sequence shown in Fig. 8

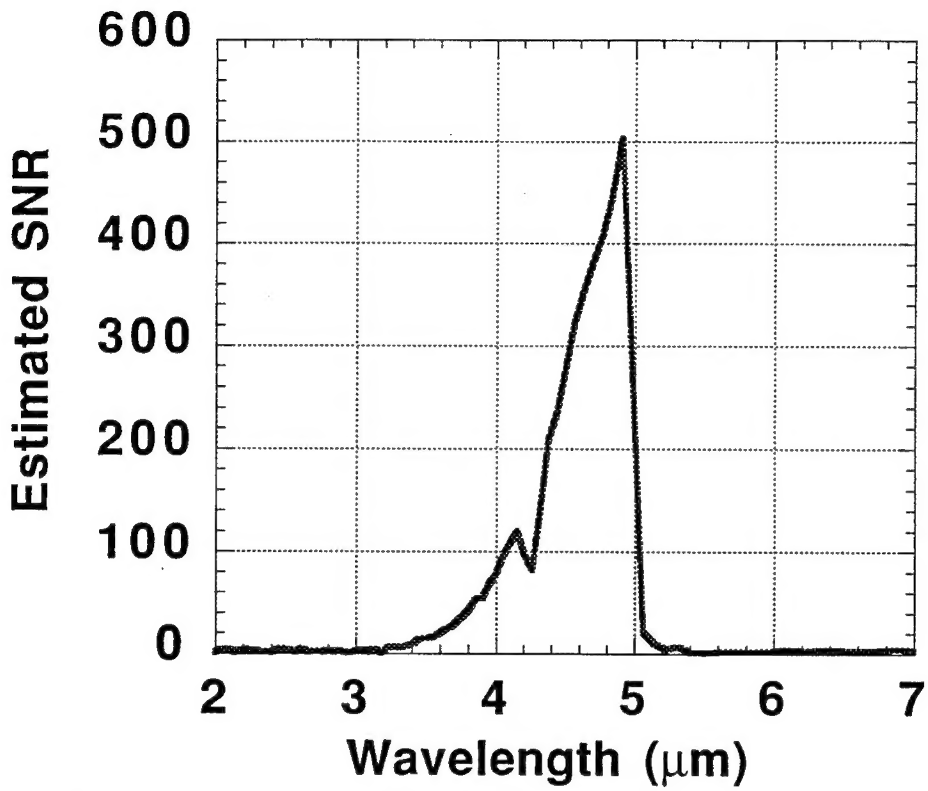

Fig. 10 — Signal-to-noise measured for a single pixel as a function of wavelength

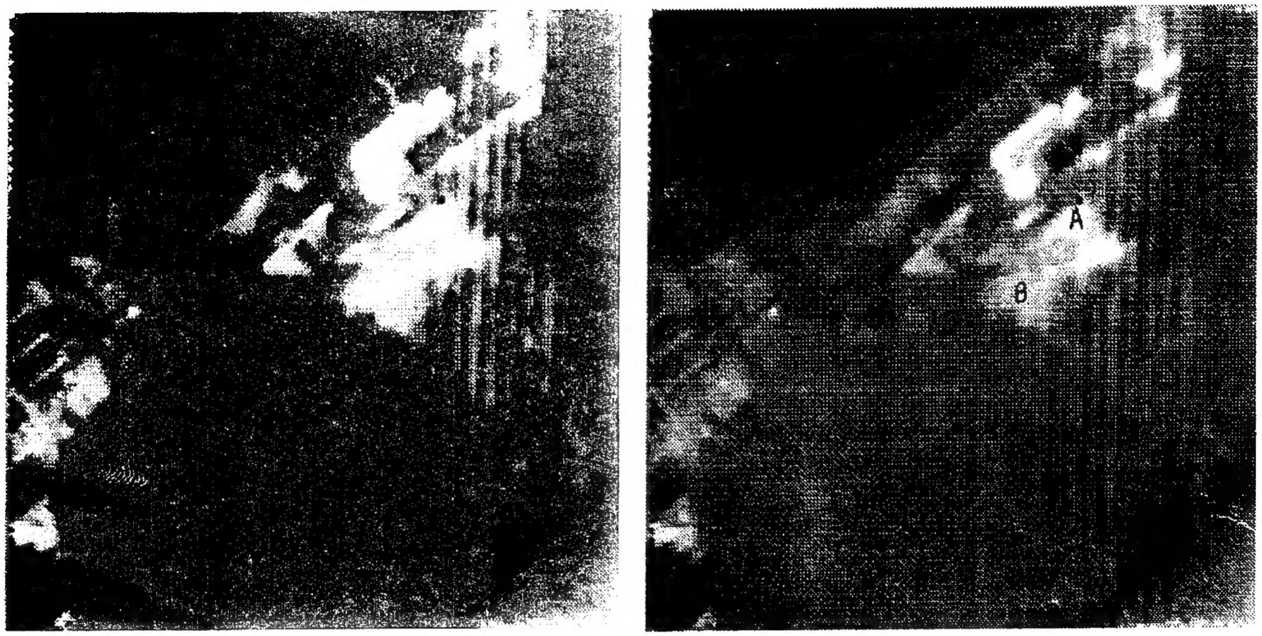

Fig. 11 — Total spectral intensity between 3.5 and 4.5 μm in false color and gray scale

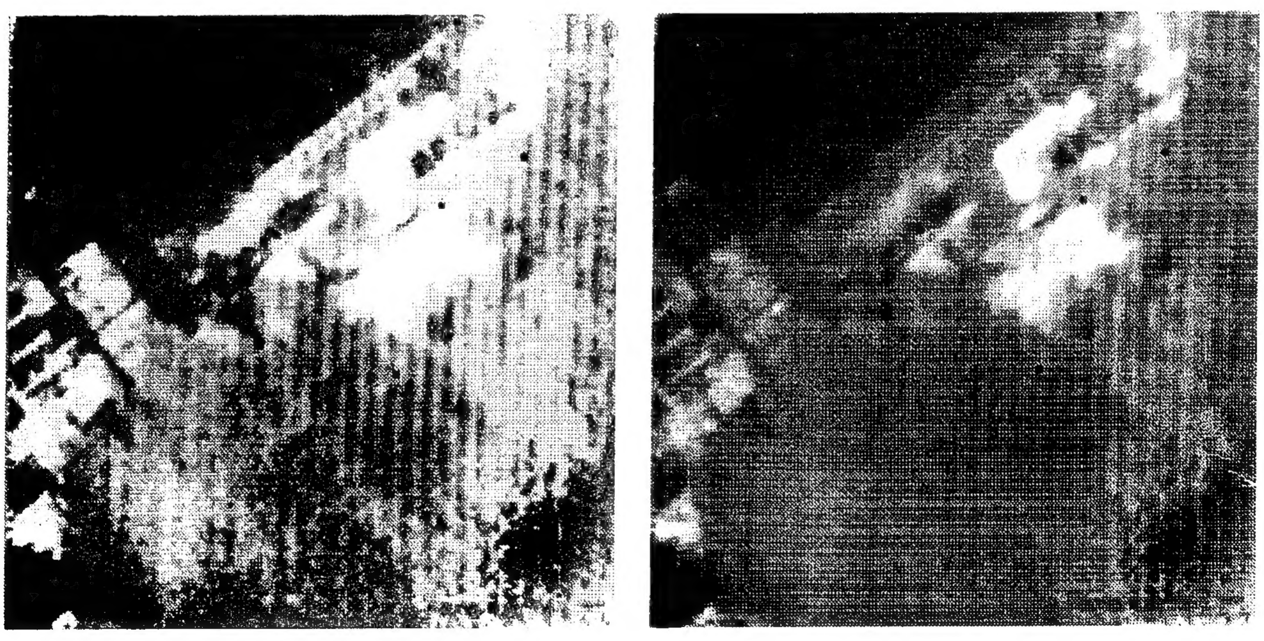

Fig. 12 — Spectral intensity at 4.76 μm

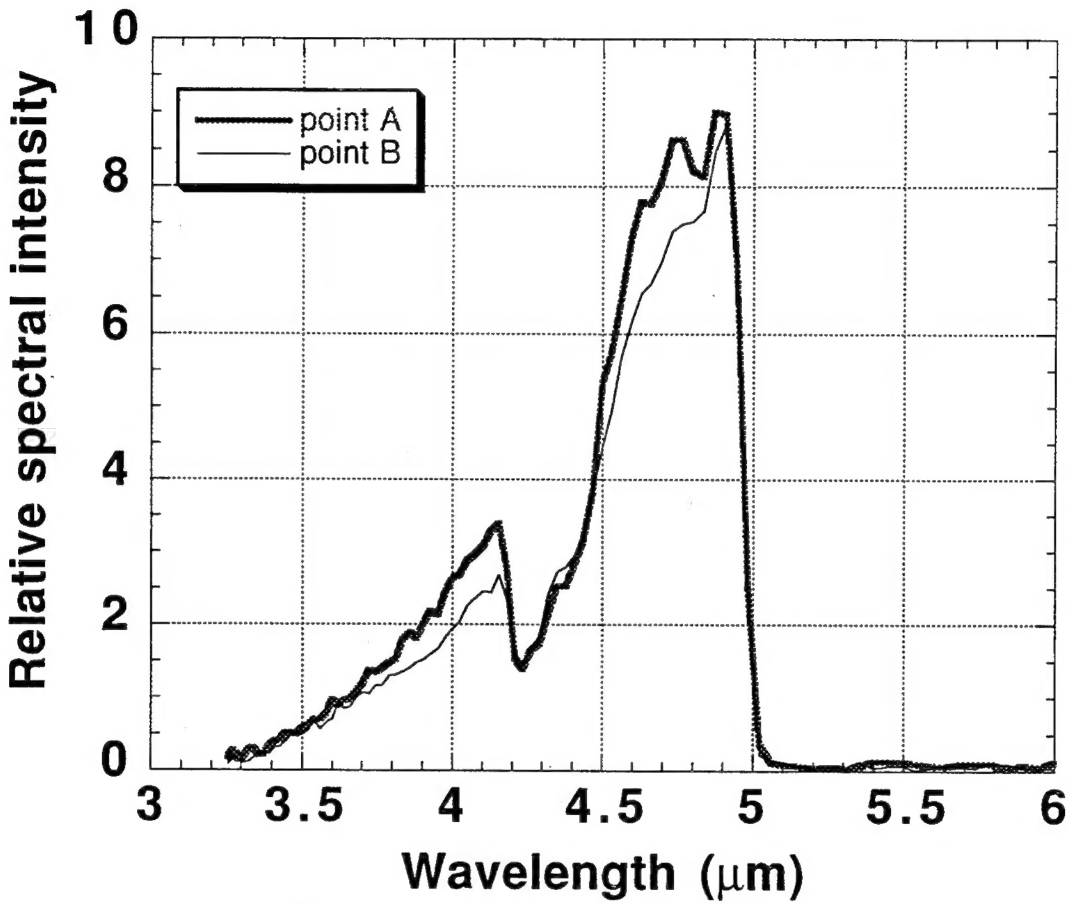

Fig. 13 — Relative spectral intensities for two points indicated in Fig. 11